HAS ENVIRONMENTAL PROTECTION REALLY REDUCED PRODUCTIVITY GROWTH?

WE NEED UNBIASED MEASURES

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FOREWORD

To a remarkable extent, policies to promote human progress depend on how progress is defined. In the industrialized world over the past century, progress has been measured mostly in terms of economic efficiency and growth. Adverse environmental, social and health impacts of economic change have never been tallied up as costs.

Productivity, which measures the efficiency with which firms transform materials and labor into products, is one of the sacred economic icons. Managers care about productivity growth because when it goes up the message is that their firm's ability to compete with others and to improve profitability and market share is improving. Workers care about it because it justifies wage increases. Economists care because productivity growth accelerates economic expansion.

Because this key economic indicator began to lag in the United States in the early 1970s, just when our major environmental laws went onto the books, some have argued that the cost of complying with environmental regulations has been responsible for the productivity slowdown. According to some studies, regulations may have been responsible for up to half of the productivity decline observed in pollution-intensive industries.

This shows how flaws in the lens through which we look can seriously distort our view of the world. The way the United States and other industrialized countries have been measuring productivity growth fundamentally misrepresents the industrial process and inevitably tells us that environmental protection reduces productivity—no matter how great the damage that is prevented. Why? Because in measuring productivity growth, we now take into account only pollution abatement costs and ignore pollution damages averted.

Why do governments and economists continue to use such a misleading indicator? The reason is fairly simple: waste products, though an inevitable consequence of production processes, do not have market prices, so their incremental cost to the economy is difficult to measure—difficult, but by no means impossible.

This study shows that an unbiased productivity measure that makes much more economic and engineering sense can be used instead of the current flawed indicator. In this measure, the cost of emissions to the economy is included in the calculation.

Doing so changes the picture dramatically. Since our environmental laws were enacted, many

industries have dramatically reduced their emissions relative to their salable outputs. This improvement in the output mix is a form of efficiency gain. An unbiased productivity measure reflects this fact and shows that environmental protection has significantly raised productivity over the past two decades.

Case studies of the electric power, pulp and paper, and agricultural sectors illustrate how this methodological change influences the record of productivity growth. According to the conventional measurement, productivity in the electric power sector declined from 1970 through 1991 at an annual average rate of -0.35 percent per year; after taking account of the substantial increase of kilowatt hours per ton of emissions, the revised record shows that productivity in the industry didn't decline at all but may have increased by as much as 0.68 percent per year. Similar but smaller distortions were found for the pulp and paper and agriculture sectors.

These case studies show that enough information is already available to revise the conventional productivity measurement. This report calls on the Bureau of Labor Statistics to work with the Environmental Protection Agency to revise productivity growth estimates for pollution-intensive sectors. It also calls on the Council of Economic Advisors to reflect such estimates in its annual economic report to counter fallacious claims that a good environment is incompatible with a strong economy.

The methods outlined in this report can also be used by companies to measure their progress toward eco-efficiency. Doing so would give environmental managers a useful new tool for priority setting.

This pathbreaking study reflects WRI's continuing effort to rethink conventional measures of economic activity in the new context of sustainable development. In *Wasting Assets: Natural Resources in the National Income Accounts* and *Accounts Overdue: Natural Resource Depreciation in Costa Rica*, Dr. Repetto showed how the national income accounts should be revised to treat natural resources as economic assets. In *Jobs, Competitiveness, and Environmental Regulation: What are the Real Issues*, Dr. Repetto showed that environmental protection requirements have not contributed to job loss or reduced international competitiveness for U.S. companies. In *"Trade and Sustainable Development,"* he argued that environmental protection and trade liberalization can complement each other if sensible policies are followed.

Essential financial support for this work on productivity measurement has been provided by the John D. and Catherine T. MacArthur Foundation and by the U.S. Environmental Protection Agency.

JONATHAN LASH
PRESIDENT
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OVERVIEW AND RECOMMENDATIONS

A. WHY IS PRODUCTIVITY GROWTH IMPORTANT?

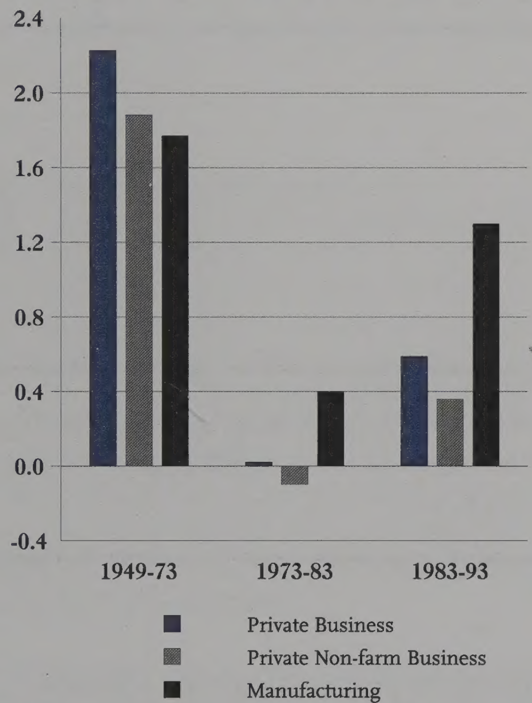
Productivity is a key indicator of technological and organizational efficiency.

Productivity—the efficiency with which the economy transforms inputs into outputs—is important because it largely determines real incomes. American living standards are high not only because our workers have more equipment and resources to work with, but also because we use labor and other resources efficiently. By contrast, the economy of the former Soviet Union, which also commanded a huge natural resource base and which invested heavily, faltered badly because those inputs and the well-educated labor force were used with low productivity.

Productivity can be measured in different ways: labor productivity measures output per worker; multifactor productivity—a broader indicator—measures the productive efficiency of labor, capital, and other inputs in combination. Either way, productivity is a key indicator of technological and organizational efficiency.

Over time, the productivity growth rate means even more because it influences how fast real incomes can rise. If the availability of goods and services were limited entirely by the gradual increase in the labor force and capital stock, then our living standards today would not be as high as they are. For example, from 1948 through 1993, U.S. agricultural output rose at an average annual rate of 1.7 percent, though overall input use actually declined (USDA, 1996b). Rapid productivity gains made the difference. Rapid productivity growth throughout the economy fueled the boom in real incomes during the 1950s and 1960s; slow productivity growth since then has inhibited real wage increases.

Figure 1.1 U.S. MULTIFACTOR PRODUCTIVITY TRENDS (1949–93)



Source: Adapted from "Multifactor Productivity Trends, 1994" (BLS, 1996)

Productivity growth also affects the fortunes of countries and firms. If U.S. productivity growth lags behind that of other countries, then, to compete in international markets, real wage levels in the United States must also rise more slowly. These effects are also felt by individual firms. When productivity growth rates exceed those of rival firms, market share and profitability should increase. Accordingly, for business managers, productivity growth within the firm reflects organizational efficiencies achieved in production; for engineers and technicians, it measures the success of productive innovation.

No wonder then that productivity growth rates are closely watched. The marked decline in the U.S. productivity growth rate first observed in the 1970s caused widespread concern. After decades of rapidly increasing prosperity, this sudden decline cast doubt on the economy's ability to provide rising living standards. Multifactor productivity in the private business sector, which had been growing at an average annual rate of 2.2 percent throughout the period 1949-1973 remained static between 1973-79; worse still, private non-farm business productivity showed an absolute decline of -0.1 percent per year for the 1973-83 period, implying that the same inputs produced less output at the end of the period than they had ten years earlier. Reinforcing these concerns, productivity growth rates have remained persistently low throughout the 1980s and early 1990s (BLS, 1996). *(See Figure 1.1)*

Productivity growth in the United States has also been well below levels recorded in other countries. Between 1973 and 1979, the United States exhibited the poorest productivity performance of all major industrialized nations, with an average annual decline of 0.4 percent. Productivity growth in the U.S. remained relatively weak during the 1979-94 period, being surpassed by Japan, France, Italy and the UK, among others (OECD, 1995). *(See Table 1.1.)* A closer look at recent years, however, reveals the U.S. making gains on other nations.

This abrupt slowdown prompted an outpouring of studies that sought to identify the cause and

Table 1.1 **INTERNATIONAL COMPARISON OF BUSINESS SECTOR MULTIFACTOR PRODUCTIVITY (1960–94)**

Average Annual Percentage Change

Country	1960-73	1973-79	1979-94
US	1.6	-0.4	0.4
Japan	5.6	1.3	1.4
Germany	2.6	1.8	0.4
France	3.7	1.6	1.3
Italy	4.4	2.0	0.9
UK	2.6	0.6	1.6
Canada	2.0	0.6	-0.1
Rest OECD[1]	3.1	1.0	1.0

Source: OECD Economic Outlook 58, December 1995

1. Australia, Austria, Belgium, Denmark, Finland, Greece, Ireland, Netherlands, Norway, Portugal, Spain, Switzerland

provide a basis for corrective policies. Economists hypothesized that payoffs to R&D expenditures had declined; that reductions in public spending on core infrastructure had affected private productivity gains; and that the growing importance of the service industries made productivity improvements increasingly difficult to measure (Aschauer, 1989; Fischer, 1988; Baily, 1986). But, despite suspicions, no such culprit was ever convicted (Munnell, 1990; Gordon, 1981).

Instead, it was generally accepted that three "shocks" to the economy were important. The first was the oil shock of the 1970s. Productivity levels declined worldwide just as energy prices rose sharply, though energy's share in GNP was sufficiently small that only one-tenth of a percentage point of the overall slowdown could be attributed directly to the price rise (Gordon, 1981). However, the sudden rise in prices may have made many energy-inefficient factories uneconomic, with the result that machinery was scrapped prematurely or severely under-utilized—lowering the productivity of the capital stock (Baily, 1981). The second shock was felt in the 1970s as the baby boomers came of age and women's labor force participation rates increased. The large influx of inexperienced labor into the workforce may have depressed labor productivity (Baily, 1986).

The third shock was environmental regulation. It has been argued persistently that the cost of complying with the Clean Air Act, the Clean Water Act, and other environmental regulations enacted in the early 1970s required industries to divert investments toward the installation of costly abatement technologies and raised production costs. Many economic studies—some of which are reviewed below—claim that environmental regulations have been responsible for up to half of the productivity decline observed in pollution-intensive industrial sectors since 1970.

This finding continues to resonate in current environmental policy debates. Behind efforts to

weaken environmental laws or their enforcement lies the belief that such regulations impose costly burdens on the economy, stifling innovation and lowering productivity. To take a recent example, *The Economist* recently stated in recommending restrictions on government regulation, "On top of all the costs of complying with the rules, there is the cost—unknowable but possibly large—that regulation imposes in the form of lost productivity. Many economists believe that over-zealous environmental regulation contributed to the great productivity slowdown that took hold in industrial countries after 1973." (*The Economist*, 1996)

However, the conclusion that environmental regulations have reduced the rate of productivity growth is an artifact of a basic flaw in the way productivity is measured—a methodology that counts the cost of environmental protection but ignores the cost of environmental degradation. This problem in productivity measurement has led to serious misunderstandings about the effects of environmental policies on the economy and to distortions in the policy-making process. The choice of which costs to measure and value and which to ignore influences our perception of what is worth doing, and so infiltrates public and private decisions. Vice President Al Gore described this subtle but pervasive influence on policy-making clearly in his book *Earth in the Balance*: "...our current system of economics arbitrarily draws a circle of value around those things in our civilization we have decided to keep track of and measure. Then we discover that one of the easiest ways to artificially increase the value of things inside the circle is to do so at the expense of those things left outside the circle." (Gore, 1992, p.189) He continues, "This partial blindness in the way we account for the impact of our decisions on the natural world is a major obstacle to our efforts to formulate sensible responses to the strategic threats now facing the environment." (Gore, 1992, p.191)

The remainder of this report explains the flaw in productivity measurement, shows how it distorts the measured impact of environmental improvement on the economy, and proposes a better way of measuring productivity growth. Case studies of the electric power, pulp and paper, and agricultural sectors illustrate what difference this methodological change would have on the record of productivity growth.

B. HOW IS PRODUCTIVITY CURRENTLY MEASURED?

Until 1983, productivity figures produced by the Bureau of Labor Statistics (BLS) were expressed in terms of output per hour worked—a simple measure of labor productivity. Now, BLS uses a more sophisticated measure that distinguishes among many different categories of labor. It is computed as the ratio of an index of outputs weighted by their respective market prices to an index of various categories of labor services weighted by their respective employment costs. After adjustment for inflation, the change in this index over time is taken as the measure of labor productivity growth.

This labor productivity indicator reflects not only changes in technology and the reallocation of labor to higher-valued occupations but also changes in the availability of capital per worker—a result of capital accumulation rather than of improved labor efficiency. For this reason, the Bureau of Labor Statistics followed the lead of academic economists and introduced a broader measure of multifactor productivity (or total factor productivity) to measure the efficiency with which all inputs are used—capital and materials

as well as labor. This indicator includes capital and materials used in production in the index of inputs along with labor. Each of these factors of production is made up of constituent inputs weighted by their respective costs to the firm. If industries exhibit constant returns to scale and input markets are competitive, the contribution that the increasing use of each factor makes to the growth rate of output can be determined. The remaining change—defined as multifactor productivity growth—represents the increase in output beyond that explained by mere increases in inputs, an increase attributable to technological and organizational advance.

Much time and energy has been devoted to improving the methodology and the data used to calculate these productivity indicators. The measurement of labor inputs now distinguishes between categories of labor whose effect on productivity differs because of educational attainment or accumulated experience. The measurement of capital services takes account of the age and relative efficiency of plant and machinery. Finally, the measurement of output has been improved by distinguishing quality improvements along with quantitative increases in the output of goods and services.

To be sure, numerous difficulties remain. Measuring output is still problematic in service industries, such as the legal profession and banking, where the nature of the end product is hard to define or may change from year to year. On the methodological side, the index used may imply unrealistic assumptions about the production process. Despite these remaining problems, in most respects productivity measurement has become more sophisticated and informative over the last 15 years. Unfortunately, in dealing with environmental protection issues, this is not so.

C. THE CONVENTIONAL APPROACH TO ASSESSING ENVIRONMENTAL PROTECTION'S IMPACT ON PRODUCTIVITY

The current methodology leads almost inevitably to the conclusion that environmental protection reduces productivity growth. Though this perception is reinforced by extensive empirical work, it is basically an artifact of the methodology now being used and is not necessarily correct. Environmental regulations have induced firms to reduce emissions by altering production processes, mainly by installing pollution-abatement equipment (e.g., exhaust gas scrubbers and wastewater treatment plants). Purchasing inputs whose main function is to curb pollution has raised input costs with no corresponding increase in marketed outputs. Thus, since the productivity measure gives industries no "credit" for reducing emissions, however damaging, measured productivity has been depressed.

Even under more flexible regulatory systems that allow firms to decide for themselves how best to meet standards, the result is much the same: the means of pollution abatement may be different and perhaps more cost-effective, but qualitatively the result will still be higher input costs with no offsetting rise in production. For example, when faced with lower sulfur dioxide emissions standards in 1992, most electric power utilities switched to low-sulfur coal to meet the requirements as cheaply as possible. Since low-sulfur coal costs more but produces no more energy, measured productivity still suffered.

The current methodology for computing productivity leads almost inevitably to the conclusion that environmental protection reduces productivity growth.

Only if steps taken to reduce emissions actually reduce production costs or raise the value of salable outputs sufficiently would environmental protection measures raise productivity as currently measured. Sometimes, of course, this happens, especially when firms solve emissions problems by fundamentally redesigning their products or production methods (Schmidheiny, 1992). Many firms have reported such successful experiences, and well-known business school professors have argued that environmental regulation can raise productivity by forcing firms to rethink their long-embodied operating systems (Porter, 1991, 1990). However, such cost-reducing examples are generally regarded as the exception rather than the rule (Oates et al., 1993). Were they typical, profit-maximizing firms would seek out such cost-saving opportunities even in the absence of environmental regulation. Typically, the current methodology leads to the conclusion that environmental protection measures lower productivity, no matter how favorable the ratio of benefits to costs.

In econometric studies dating from the 1970s, environmental protection has been found to retard productivity growth. An early study of the private sector between 1972 and 1975 (Denison, 1979) concluded that 16 percent of the decline in productivity growth could be attributed to environmental regulations. Haveman & Christainsen (1981) reported that 8 to 12 percent of the decline in productivity in the manufacturing sector between 1973 and 1975 was due to regulation, a finding mirrored by that of Gray (1987) for 1973-78. Meanwhile, for the same period, Norsworthy et al. (1979) attribute 12 percent of the downturn in labor productivity to environmental compliance.

A more recent study of five U.S. manufacturing industries (Paper; Chemicals; Stone, Clay and Glass; Iron and Steel; and Non-ferrous metals) attempted to measure separately the direct effect of having to buy abatement capital and the indirect effect of having to alter input combinations to accommodate the new equipment (Barbera & McConnell, 1990). After comparing annual average productivity growth figures for the period 1960-70 and 1970-80, the authors concluded that between 10 percent and 30 percent of the observed decline could be attributed to the overall effect of the introduction of abatement capital, of which one-half represented a direct effect. Other studies have considered the productivity effects felt in Canada and Germany (Conrad & Morrison, 1989) and Japan and Germany (Nestor & Pasurka, 1993), among other countries. With some exceptions, the findings abroad have mirrored those in the United States.

Studies of the electric utility sector, which faced some of the most costly abatement requirements, have estimated greater productivity losses than in manufacturing industries. For the period 1973-79, 44 percent of the recorded productivity decline in this sector was attributed to environmental regulation, equivalent to a reduction in annual productivity growth of 0.59 percentage points (Gollop & Roberts, 1983). For the shorter period 1975-79, when the industry was attempting to comply with EPA air quality

standards, the estimated impact was an even larger—0.88 percentage points per year. Crandall (1981) also found evidence for the relatively heavy burden regulation imposed on the electricity generating sector.

Fare, Grosskopf & Pasurka (1986) estimated the effect of regulatory restrictions on the technology used in 100 steam electric plants in 1975. They found that these restrictions "'cost' an average of roughly 16 million kilowatt hours in lost potential output for each plant" (Fare et al., 1986 p. 184). This was in addition to the monetary outlay for pollution abatement equipment. Furthermore, the authors claimed, these costs almost certainly increased after 1975 as federal regulations were implemented.

A study of individual steel-making plants in the United States for the period 1979-88 found that each additional dollar in environmental operating expenditures ultimately raised marginal costs by $7-12 per ton of output (Joshi 1995). Gray & Shadbegian (1993) found a similar regulatory impact on plant-level productivity for pulp and paper mills, oil refineries and steel mills. Their initial study estimated that for every $1 of compliance expenditure, there was a further $3-4 cost increase from indirect effects. However, in follow-up work, they found a much smaller indirect effect (Gray & Shadbegian, 1994).

In the most recent study of this kind, Robinson (1995) estimates statistically the effects of environmental protection expenditure on productivity growth across 445 U.S. manufacturing industries and finds a significant negative effect. He concludes that "the productivity-reducing burden of past regulation haunts the future of environmental...policy" (p. 417).

These studies differ in their analytical approach, the time period, and the industries under observation, but all conclude that the response to environmental regulation has impeded productivity growth. Whether intended or not, the inevitable consequence of this consensus has been to strengthen the impression that environmental protection hinders economic growth and reduces living standards. Unfortunately, however, this conclusion is an artifact of the assumptions underlying the definition of productivity. A more reasonable definition would lead to different conclusions.

D. WHY ARE STUDIES USING CONVENTIONAL METHODOLOGIES BIASED AGAINST ENVIRONMENTAL PROTECTION?

The productivity measure used in all these studies rests on an incomplete depiction of industrial processes. Basically, industries transform material and energy inputs into marketed outputs. These transformations conform to physical laws, including the conservation of matter and energy, which dictates that all the raw materials drawn into an industrial process re-emerge in some form. An industrial engineer can lay out a materials and energy balance for any industrial process and show where all the inputs go, some to product and some to waste streams. They all go somewhere: in the words of Sesame Street's Big Bird, "You can't make nothing out of something."

For example, a typical 500-megawatt coal-fired power station produces not only 3.5 billion kilowatt hours of electricity per year—the measured 'output'—but also 5,000 tons of sulfur oxides, 10,000 tons of nitrogen oxides, 500 tons of particulate matter, 225 pounds of arsenic, 4.1 pounds of cadmium, and 114 pounds of lead, as

well as trace amounts of other minerals embedded in the coal. All the 1.5 million tons of coal burned each year in the plant for energy ends up as ashes, emissions, and other waste products, including more than a million tons of carbon, virtually all of which is emitted as carbon dioxide. The plant also generates a good deal of waste heat, which is usually dispersed in cooling waters. The conservation of matter and energy dictates that along with useful outputs—electricity, in this example—industrial processes also inevitably generate residual outputs that are potentially damaging when released to the environment.

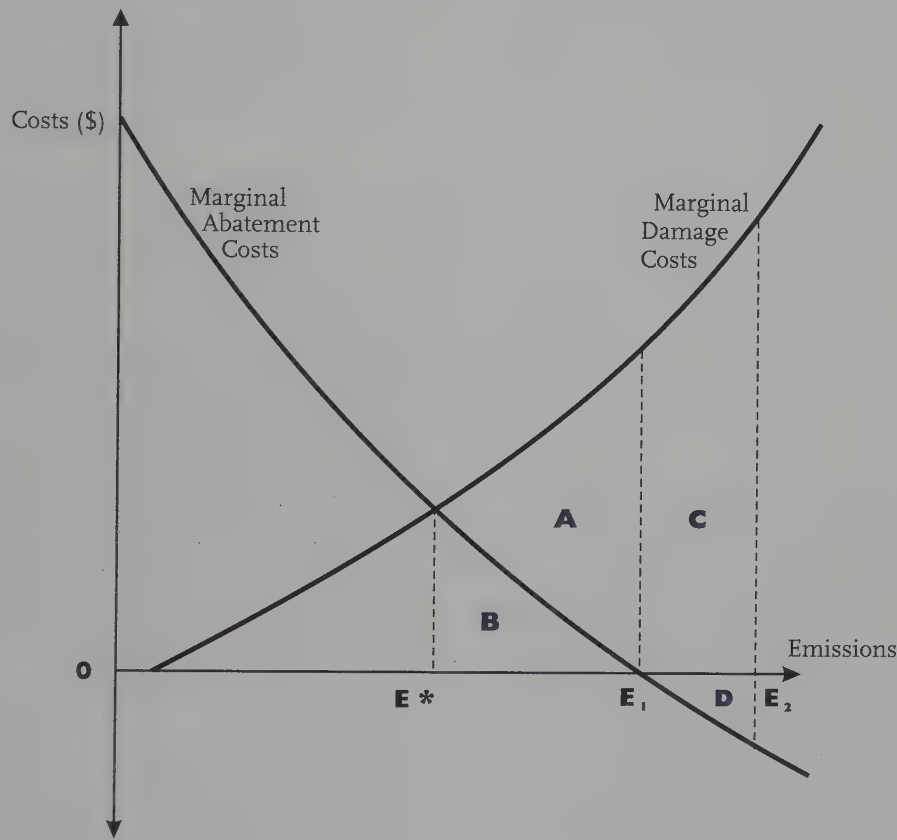
Huge flows of unsalable residuals discharged at all stages of the production cycle generate important economic costs and environmental impacts that are assumed away in measuring productivity growth.

When industrial production is considered in its entirety like this, it's obvious that in physical terms inputs and outputs must grow at the same rate. The right question, then, is whether industrial processes transform these inputs into outputs of greater value, recognizing that some outputs are valuable when sold and that others are damaging when released. Conventional productivity measures generate differential growth rates for inputs and outputs only by ignoring an entire class of outputs, those that are a nuisance to society and therefore unsalable. The productivity index counts the electricity that is produced but ignores all the other less desirable outputs of the process, even though they are significant in economic terms. The result is an incomplete and misleading indicator of efficiency—one that misrepresents the underlying process, and that is inconsistent with the laws of physics.

Ignoring wastes and residuals is by no means a trivial omission—they are huge. Each year, to generate nearly 5 billion tons of salable commodities, the U.S. economy uses more than 10 billion tons of crude materials, generating at least 5 billion tons of waste materials—largely mining wastes. Further processing and fabrication of these basic commodities generates several hundred million more tons of wastes and effluents that are discharged into the environment. In addition, approximately 2 billion tons of commodities—predominantly fossil fuels and agricultural chemicals—are used in ways that dissipate the material in the environment. All in all, at least 8 billion tons of materials are discharged to the environment every year, aside from those additional materials eventually discarded as post-consumer waste (Repetto, 1996). These huge flows of unsalable residuals discharged at all stages of the production cycle generate important economic costs and environmental impacts. Nonetheless, they are assumed away in measuring productivity growth.

Though the resulting measure of efficiency rests on a model of the profit-making firm operating in competitive markets, it disregards the concept of efficiency that economists use to evaluate environmental protection measures explicitly. This basic concept of environmental economics, which recognizes that there are no markets for most effluents discharged into the environment, is portrayed in Figure 1.2. In the diagram two curves represent the costs of pollution damage

Figure 1.2 EFFICIENT POLLUTION ABATEMENT



and the costs of pollution abatement at different levels of emissions. Specifically, the Marginal Damage curve (MD) measures the damage in monetary terms caused by the last (or 'marginal') unit of pollution. Though expressed in monetary terms, these non-market damages might include illness among the exposed populations, degradation of natural resources that makes them less valuable to users, damages to buildings and materials from exposure to pollutants, and other environmental impacts. If all units of pollution were equally harmful, this line would be horizontal. Instead the MD curve slopes upward, reflecting the tendency for an additional unit of emissions at low levels of pollution to cause proportionately less damage than an additional unit at high levels. At low levels, the effects of emissions may be negligible because of the natural absorption capacity of the environment, which ensures that an extra unit results only in limited damage. However, as emissions increase, it becomes more likely that critical thresholds will be passed, so the addition of an extra unit has greater impact.

The marginal abatement cost curve (MAC) shows the costs to the firm of removing the final unit of pollution. Again, this cost varies according to the initial level of emissions. At high emission levels, the cost of removing a unit of pollution should be low—or even negative, if the firm can save materials or reduce costs through housekeeping improvements. If the firm is currently doing little or nothing to reduce pollution, relatively cheap and easy abatement options are likely to be available. However, as overall emissions levels are reduced, it becomes harder and more expensive to make further cuts. The MAC curve reflects the extra input costs to the firm of various abatement options, assuming it will implement the least expensive ones first.

The efficient amount of emission reduction occurs at the intersection of the two curves, where the marginal damage costs equal the marginal abatement costs. At higher levels of emissions, the costs of reducing pollution by a unit (equal to MAC) are lower than the damage costs associated with this unit (equal to MD). Hence, efficiency increases if this unit of pollution is removed. If emissions levels are reduced further than this, the higher costs of removing these units are not justified by the meager reduction in damages. Emissions reduction is efficient when the incremental costs of pollution control are balanced against the incremental costs of pollution damage.

The current methodology of productivity measurement completely ignores this efficiency criterion. Referring again to Figure 1.2, consider a firm that generates E_2 emissions in producing its marketed output. The diagram depicts a situation in which emissions are so high that both emissions and input costs can be reduced simultaneously. Using conventional productivity accounting, a reduction from E_2 to E_1 would be recorded as a productivity increase corresponding to area D, the total input cost saving. However, this understates the true efficiency gain because it ignores the reduction in environmental damage from lower emissions, equal to area C.

Worse still, cutting emissions further from E_1 to E^*, which would actually maximize efficiency, would cause conventionally measured productivity to *fall* (by an amount equal to area B) because the firm incurs abatement costs with no increase in sales revenues. Despite this reduction in measured productivity, economic efficiency actually would rise by an amount equal to area A, the amount by which the avoided costs of environmental damages exceed abatement costs. As an evaluative measure, the conventional productivity indicator is seriously misleading because environmental protection measures that actually improve economic efficiency can be recorded as lowering productivity.

A recent EPA study, prepared at the request of the U.S. Congress, provides strong evidence that this distortion has actually occurred. A very comprehensive assessment of the benefits and costs of atmospheric pollution abatement required by the Clean Air Act between 1970 and 1990 found that the economic damages averted by air quality protection over these years were around fifteen times as great as the environmental protection costs incurred (USEPA, 1996). Substantial uncertainties surround these estimates of damages averted, since not all the identified benefits could be expressed in monetary values and the estimated values were subject to error, but even the minimum estimate of benefits from air quality protection exceeded the estimated costs by a

factor of five. Nonetheless, the conventional productivity indicators used in all the studies cited above still imply that environmental protection reduced productivity growth. This strongly suggests that the current methodology does not provide a reliable indicator of environmental efficiency.

Although they have used the conventional productivity indicator, most of the authors of these studies do recognize the methodological deficiency. For example, Gollop & Roberts note that "any discussion of the desirability of environmental regulation must weigh ... benefits against the costs of regulation" (Gollop & Roberts, 1983 p. 672). Jorgenson & Wilcoxen issue a similar disclaimer and conclude that the results of their study "cannot be taken to imply that pollution control is too burdensome or, for that matter, insufficiently restrictive" (Jorgenson & Wilcoxen, 1990 p. 315). Robinson points out that "reductions in productivity should be evaluated in light of the reductions in pollution achieved through regulation" (Robinson, 1995 p. 414).

Why, then, do government and academic economists continue to use the conventional productivity indicators? The reason is that waste products emitted to the environment, unlike salable outputs, do not have market prices. As economist Tom Schelling once remarked, "The worst things in life are free." Utilities sell their electricity but are perfectly willing to give you their particulate and sulfur emissions for nothing. Undeniably, the fact that emissions lack market prices makes estimating their incremental cost to the economy difficult—but not impossible. Estimating the economic costs of pollution is the bread and butter of environmental economists; over the past 15 years EPA has funded hundreds of millions of dollars in research on pollution damages. Though subject to uncertainties, estimates do exist. Nor do these uncertainties validate the current approach, which, in effect, assigns a zero price to emissions in the index of outputs. Although quantifying the economic costs of emissions can be done only with a margin of error, "zero" is usually not a good approximation.

Government and academic economists continue to use the conventional productivity indicators because waste products emitted to the environment, unlike salable outputs, do not have market prices.

Economists have tried to devise a productivity indicator that takes account of the costs of pollution. Russell Pittman (1983) proposed a 'multilateral productivity index' that included undesirable as well as desirable outputs, valuing emissions by shadow prices approximated by marginal abatement costs (rather than marginal damage costs). Although estimates of abatement costs are more readily obtainable, using them to value emissions will misrepresent efficiency gains from environmental protection unless firms are already controlling emissions optimally. Nonetheless, Pittman's conceptual approach represents an important step forward in productivity measurement, one that unfortunately has not been followed up, even though his empirical results showed substantial differences from the conventional productivity measure.

The difficulty in estimating the costs of pollution prompted Fare, Grosskopf, Lovell & Pasurka (1989) to use data from a sample of firms within an industry to estimate a 'socially feasible output set' that includes all possible combinations of desirable and undesirable outputs. From this they estimated the minimum level of emissions that firms can produce for different levels of marketable output. Then, they defined the efficiency of a single mill by its proximity to this frontier (i.e., the extent to which its emissions exceed the minimum "needed" to produce the same level of marketed output).

This analysis does come to grips with the fact that firms inevitably produce undesirable by-products along with their marketed outputs, but it still exhibits two main limitations. First, the estimated efficiency frontier represents, at best, what firms are currently achieving, rather than what is feasible. Second, the "distance" between any firm's performance and that of the most efficient can properly be measured only if the costs of emissions are known relative to the value of marketed outputs. Recognizing this, Fare, Grosskopf, Lovell, and Yaisawarng (1993) have attempted to derive plant-specific shadow prices for emissions equal to the cost of the desirable output that must be foregone to reduce the undesirable output by one unit. Nestor & Pasurka (1994) use this methodology to derive shadow prices for six air pollutants and then incorporate these prices into a measure of productivity for 20 manufacturing sectors. The adjusted total factor productivity growth measure is, for all sectors but one (non-metallic minerals), higher than the conventional measure.

However, these shadow prices still represent marginal abatement costs, simply derived differently than in Pittman's work. In Pittman's study the abatement costs are the monetary costs of reducing pollution by installing abatement measures or equipment. In the work of Fare and his colleagues, abatement costs are estimated as the sacrifice in marketed output necessary to achieve a unit fall in emissions. In neither case do the shadow prices represent the economic costs of pollution damages.

Given the difficulty of estimating pollution damages, Gray proposes an alternative approach to revising the productivity measure—one that excludes both environmental costs and environmental benefits (Gray & Shadbegian, 1994, 1993; Gray, 1986). His approach attempts to limit the productivity indicator to measure only the efficiency of inputs devoted exclusively to the production of the marketed output. The real problem with this approach, as he recognized, is identifying which costs are undertaken solely for pollution reduction reasons. As businesses continue to de-emphasize "end-of-pipe" pollution control and redesign processes and products to prevent pollution from occurring, this distinction will be increasingly difficult to make.

E. A BETTER APPROACH

The conventional methodology used to derive the multifactor productivity index can be extended in a straightforward way to take account of environmental damage from emissions of industrial waste products. Emissions are simply considered joint outputs of the industrial process and are included in the output index with weights determined by their marginal damage costs (as opposed to marginal abatement costs).

The multifactor productivity indexes estimated by the Bureau of Labor Statistics are based on an assumed production function of the form:

(1) $Q(t) = A(t).f[K(t), M(t), L(t)]$

where Q(t) stands for real output in year t; K(t), M(t) and L(t) represent capital, material, and labor inputs, respectively; and A(t) is a productivity index. From this function the rate of productivity change index can be estimated as:

(2) $A'(t)/A = Q'(t)/Q - [s_k K'(t)/K + s_m M'(t)/M + s_l L'(t)/L]$

where the primed quantities represent rates of change with respect to time. In other words, the rate of productivity change is defined as the difference between the growth rate of the output index and the growth rate of the input index. In turn, the input index is derived by weighting each factor of production by the proportional change in output that results from a small change in that input alone (technically, the output elasticity). These weights are denoted by s_k, s_m and s_l. If there is perfect competition in both the input factor markets and the output markets and there are constant returns to scale, these weights are equal to the shares of the individual factors in total costs and, consequently, add up to one.

Environmental residuals can be incorporated into the framework by defining total output, W, as the aggregation of marketed output, Q, and emissions, E. 'Total' output exhibits a rate of growth equal to:

(3) $W'(t)/W = s_q Q'(t)/Q + s_e E'(t)/E$

According to this formula, the rate of change of total output is equal to a weighted average of the growth of output and the growth of emissions. The weights are equal to the shares of output and emissions in the total value of output. Of course, since emissions are damaging, they have a negative value rather than a benefit and so have negative shadow prices. Qualitatively, their impact on productivity is the same as that of input costs.

If A* is defined as the productivity index for the joint output function, W, then the growth rate of A* is:

(4) $A^{*\prime}(t)/A^* = s_q Q'(t)/Q + s_e E'(t)/E - [s_k K'(t)/K + s_m M'(t)/M + s_l L'(t)/L]$

Comparing (2) with (4) gives:

(5) $A^{*\prime}(t)/A^* = A'(t)/A + s_e.[E'(t)/E - Q'(t)/Q]$

where:

s_e is the weight of pollution damages in total output;

E´ is the change in pollution damages;

E is the level of pollution damages;

Q´ is the change in the value of marketed output;

Q is the value of marketed output.

Equation 5 shows how the two productivity indicators are related. Because s_e is negative, whenever emissions grow more slowly than output, the new productivity index will increase more rapidly than the conventional index. Furthermore, if output increases or stays constant, *any* decline in emissions will lead to a faster rate of productivity growth than that measured by the conventional index. Should emissions increase more rapidly than marketed outputs, however, the conventional index will overstate the productivity growth rate.

In other words, the revised methodology takes into account a source of productivity growth that the conventional methodology completely misses: a more rapid growth in the value of total output due to a shift toward highly valued marketable products and away from negatively valued waste products. Undoubtedly, this is as valid and potentially important an efficiency gain as any other. In some industries, as the following case studies demonstrate, it has been the most important source of improvement.

Calculating the new productivity measure requires an estimate of the share of emissions in total output, which is determined by both the quantity of emissions and its shadow price—the total economic damages another unit of emissions would do.

Calculating the new productivity measure requires an estimate of s_e, the share of emissions in total output. In turn, s_e is determined by both the quantity of emissions and its shadow price, which represents the total economic damages another unit of emissions would do. Damages can be of many different kinds: increased illness, reduced recreational opportunities, impairment of materials, and ecological impacts. These damages are estimated by various techniques that have been the subject of extensive research and refinement over the last 20 years (Freeman, 1993). The Environmental Protection Agency has supported a great deal of research into damage estimation and has itself been required by Congress and the Office of Management and Budget to study the benefits and costs of the environmental regulations it has proposed. Estimates of pollution damages can draw on a large store of regulatory analyses, cost-benefit assessments, and agency-sponsored research.

The wide confidence limits within which damage values are usually expressed arise partly from the complexity of the underlying physical and biological processes, each of which can be described only within some margin of error. Further variation stems from differences in valuation methodologies used in various studies. Moreover, damages from a unit of emissions will vary substantially, depending on timing and location, the hydrological or meteorological conditions around the emissions source, the size of the population affected, and other factors. Although damage studies have been carried out in many locations, extrapolating the results to other places or generalizing to larger areas also creates room for inaccuracy.

Despite their imprecision, the strongest justification for drawing on estimates of emissions damages is simply that pollution imposes real economic costs. In the study of the electric power industry reported below, it was found that sulfur emitted from generating-plant smokestacks was found to have a higher cost per ton to the economy than elemental sulfur sold as an industrial raw material. To dispense with damage estimates because they are imprecise is to implicitly impute a zero value for emissions—a figure that is contradicted by substantial evidence of pollution's adverse effects. A better conclusion is that more accurate estimates of the economic costs of pollution would be useful in several policy contexts and warrant further efforts to refine the available numbers.

Still, marginal damage estimates are available only for some kinds of emissions, not for all. For example, few credible estimates have been made so far of the global damages from an additional ton of carbon dioxide released into the environment. Nor are there estimates of the environmental costs of the large majority of toxic substances listed on the EPA's Toxic Release Inventory. Consequently, despite the adjustments made in this report to the conventional productivity methodology, the pollution damages included in the revised figures are only a subset of the total. That this subset proves to be empirically significant reinforces the argument that the conventional methodology is misleading. Complete implementation of the proposed alternative would lead to an even starker reappraisal of the conventional conclusions.

F. EMPIRICAL RESULTS

Case studies of the electric power, pulp and paper, and farming industries have reexamined the record of productivity growth since the early 1970s in three environmentally sensitive U.S. sectors. These case studies are discussed in greater detail in the following chapters. The first two sectors were substantially affected in the 1970s by the Clean Air and Clean Water Acts, as well as by later amendments, which forced them to reduce "conventional" air and water emissions substantially. These emissions included atmospheric emissions of particulates, sulfuric and nitrogen oxides, volatile organic compounds and carbon monoxide, along with water emissions of suspended solids and organic materials (expressed as biochemical oxygen demand). Regulations virtually required large emissions sources to install pollution abatement equipment on smokestacks and water effluent discharge streams.

The farming sector has not been subject to stringent environmental regulation. However, farmers have been encouraged by cost-sharing programs to implement soil conservation programs and farm management plans to reduce run-off. In addition, the Conservation Reserve Program provides a "carrot" to farmers willing to retire land from cultivation, and wields a "stick" in the form of cross-compliance provisions denying agricultural support payments to farmers who plough up highly erodible soils for additional cropland. The effectiveness of these provisions in reducing soil erosion was strengthened by rising energy prices, which induced many farmers to adopt "no-till" or "reduced-till" farming systems, using seed drills for planting and substituting herbicides for mechanical weed control.

Over this period the electric power industry in the United States ranked above the other two in emissions per unit of output. Coal has been the primary energy source, and producing a kwh of electricity (worth about $0.06) at average efficiency requires burning about a pound of coal, all of which becomes waste. Moreover, most of the resulting emissions are dispersed into the atmosphere, giving rise to a variety of environmental impacts. According to the estimates in the following chapter, the costs of atmospheric emissions in recent years amounted to about 15 percent of the value of total outputs from the sector, including good and bad outputs together. But these environmental damage costs might have been as much as 30 to 60 percent of total output value back in 1970.

Second in rank is the pulp and paper industry, a highly energy-intensive industry that uses large quantities of water in the manufacturing process as well. Both air and water emissions from this

sector are significant. Environmental damage costs declined from over 7 percent of the value of total output in 1970 to less than 2 percent in 1990. These estimated damage costs do not, however, include the effects of dioxins and other chlorinated organic compounds emitted during the bleaching process and now suspected of causing significant ecological and health harm.

Emissions from farms are large in the aggregate, but many—such as volatized nitrogenous fertilizers and pesticides leached into subsurface aquifers—remain unrecorded. Soil run-off, the only emission recorded in this study, is not terribly damaging in sparsely populated farming regions. Yet, sediments eroded from farmlands do several billions of dollars in off-site damage every year.

Consequently, one would expect that over the past 20 years the conventional productivity indicators would most distort the record of efficiency gains in the electric power sector, where the mix of "good" outputs (kilowatt hours of electricity) to "bad" outputs (atmospheric emissions) has changed dramatically. This expectation is correct. According to the conventional measurement, productivity actually declined over the period 1970-1991 at an average annual rate of -0.35 percent per year. *(See Table 1.2.)* Environmental regulations, as noted above, have been blamed for much of that decline. Using a more reasonable measure, which takes account of the substantial increase of kwh per ton of emissions, the record shows that productivity actually increased by an average rate of 0.38 to 0.68 percent per year. The discrepancy between the conventional and revised estimates is even wider for the 1970s, when the industry came into compliance with Clean Air and Clean Water Acts. The main source of productivity gain was not improved output per unit of labor, capital, or fuel input; rather, it was improved output per unit of emissions.

One would expect that over the past 20 years the conventional productivity indicators would most distort the record of efficiency gains in the electric power sector, where the mix of "good" outputs to "bad" outputs has changed dramatically. This expectation is correct.

Similar but smaller distortions were found for the pulp and paper, and agriculture sectors. The conventional methodology understates the annual average rise in productivity in the pulp and paper industry by a factor of two or three. Revised estimates suggest that productivity rose by 0.36 to 0.44 percent per year over the 1970s and 1980s, but according to the conventional methodology, the rate of increase was only 0.16 percent annually. By neglecting the dramatic shift in industry outputs toward higher valued products (i.e., paper that people might wish to buy rather than pollutants they would rather do without), the conventional measure understates substantial gains in economic efficiency.

The difference between conventional and revised estimates is smallest for the agriculture sector, in which environmental damage costs form the smallest fraction of total output. The conventional indicator understates actual

Table 1.2 SUMMARY OF MAIN RESULTS

Sector	Period	Multifactor Productivity (average annual percentage change) Conventional MFP	Revised MFP (constant damage values)	Revised MFP (damage values proportional to GDP)
Electricity	1970-91	-0.35%	0.68%	0.38%
Pulp & Paper	1970-90	0.16%	0.44%	0.36%
Agriculture	1977-92	2.30%	2.41%	2.38%

productivity growth by no more than 0.11 percentage points over the period 1977-1992. However, for two reasons, the estimates reported here are probably an underestimate of the required adjustment. First, as mentioned earlier, the only residual 'output' that could be tracked and evaluated was eroded agricultural soil; runoff of agricultural chemicals and organic wastes, both of which do additional damage, were not included in the accounting. Second, the market value of agricultural commodities, the salable part of farm output, is inflated by a variety of government programs, including commodity price support programs for cereals, import restrictions for sugar, and marketing restrictions for fruits and dairy products. For both reasons, the significance of effluents in total output is understated.

Taken together, the case study results provide some indication of the extent of the measurement problem. For heavily polluting industries, such as chemicals, metals, non-metallic minerals, mining, oil and gas, and transportation, the conventional productivity measure probably significantly understates productivity gains during the last two decades. Moreover, as these industries continue to reduce their emissions, the current productivity measures will continue to give distorted results.

For heavily polluting industries, the conventional productivity measure probably significantly understates productivity gains during the last two decades.

For industries that generate few effluents directly, such as financial and other services, retailing, and entertainment, the productivity measures are hardly affected at all by leaving out environmental damages. For other manufacturing industries, such as textiles or electronics, in which pollution damages represent a small share of total outputs, the required adjustment would likely be relatively small but not necessarily insignificant.

An estimate of the adjustment to the economy-wide productivity record the revised methodology implies was developed by applying the adjustment estimated for the pulp and paper industry (0.3 percentage point per year) to other pollution-intensive industries as well, including chemicals, petroleum and coal, primary and fabricated metals, mining, and non-metallic

mineral products. In addition, the adjustment estimated for the electric power industry (1.0 percentage point per year) was factored in. No adjustments were made to the conventional productivity growth measures for other industries, although many of those industries also reduced emissions per unit of output. The result indicates that over the period 1970-1991, productivity growth in manufacturing and private non-farm business was understated by 0.12-0.14 percentage points per year. This represents a 12 percent understatement of the historical growth rate of manufacturing productivity, and a 32 percent understatement of productivity growth in the broader economy encompassing all non-farm private business. Thus, the distortion in the measurement of economic efficiency gains in the U.S. economy overall has been substantial.

G. CONCLUSIONS AND RECOMMENDATIONS

The implications for agencies concerned with productivity growth and with environmental protection in the U.S. economy are clear. It is important to introduce an unbiased measure of productivity that accurately captures the economic impacts of environmental protection, on which we now spend about 2 percent of GDP. Such a measure would record the costs averted as well as the costs incurred throughout the economy as environmental quality is protected. It would also record more accurately the record of economic progress in environmentally-sensitive industries. This measure need not necessarily supplant, but should surely supplement, existing statistics.

Preparing and maintaining a revised record of productivity growth depends on an adequate information base. The Environmental Protection Agency has made great strides in developing environmental databases, using them for economic analysis and making them publicly available. The EPA should develop and publish consistent time-series data on regulated air and water emissions on an industry-by-industry basis. In the past, EPA has classified these data by emissions source category (e.g., "industrial boilers"). They should be cross-classified by industrial sector, using the standard industry classifications. Having such time-series records of emissions trends would be useful not only for estimating productivity growth, but also for other important purposes. For example, efforts to develop cross-media industry-wide pollution reduction plans as alternatives to detailed command-and-control regulations depend for accountability on reliable environmental performance indicators, especially trends in emissions.

EPA should also continue to increase the availability of credible estimates of marginal pollution damages, the other essential information needed to revise productivity measures. The recent retrospective estimates of the benefits and costs of the Clean Air and Clean Water Acts provides a treasure trove of information that can be used for this purpose, but these analyses must be manipulated to generate estimates of the *marginal* damages from small decreases in emissions below various initial levels. Moreover, EPA should continue to fund and carry out research to estimate the marginal damage costs of pollutants for which current knowledge is lacking or inadequate. Such information will be highly useful not only for productivity measurement but also for priority setting in environmental policy, regulatory analysis, and other purposes. This information should be accessible to researchers outside of government as well.

However, insight need not await the results of further research. Sufficient information on these building blocks of productivity measurement is already available to permit the conventional estimates to be revised, at least for environmentally sensitive industrial sectors. The Bureau of Labor Statistics, which is the lead federal agency for productivity measurement, should undertake a joint study with EPA to develop a revised set of productivity growth estimates for pollution-intensive sectors using the basic methodology set out in this report. These revised estimates should cover the last 20 to 25 years, to capture the true impact of environmental protection on U.S. productivity. They should also be updated and published regularly in Bureau of Labor Statistics publications.

Informed discussion of the true impacts of environmental protection on the national economy is highly desirable. In the past, discussion has tended to be rather one-sided since the costs of controlling pollution can be quantified and estimated much more readily than the costs of *not* controlling pollution. To promote informed discussion, the Council of Economic Advisors, in its influential annual *Economic Report of the President*, should include revised estimates of productivity growth in environmentally sensitive industries in its chapters on regulatory reform and economic efficiency. The Council on Environmental Quality should also take notice of these revised estimates in its annual report.

As noted earlier, individual companies are also keenly interested in their own productivity records, and, companies in environmentally sensitive industries are searching for performance metrics and indicators that can adequately reflect their individual progress toward "eco-efficiency." The methodology outlined here can readily be adapted for this purpose. It would measure efficiency gains in the use of conventional inputs—capital and labor as well as raw materials and intermediates. In addition, it would measure progress in reducing emissions and effluents. Estimates of damage costs would have to be particularized to each company's own sites and the composition of its waste streams. However, doing so would provide environmental managers with information useful in priority setting. Environmentally progressive companies that begin tracking their own productivity improvements using this basic methodology will be better able to integrate their environmental- and business-management practices.

2

ENVIRONMENT AND PRODUCTIVITY IN THE ELECTRIC UTILITY SECTOR

Throughout the 1970s and 1980s the U.S. electricity industry consisted mainly of vertically integrated, investor-owned companies generating and distributing electricity within regional franchise areas. These local monopolies were regulated by state public utility commissions that typically set electricity tariffs to allow target rates of return on invested capital. Most generating plants were coal-fired, though nuclear plants contributed a rising fraction of electricity generated during the 1970s, peaking at about 25 percent and then declining during the 1980s.

Costs and productivity in the industry were adversely affected during this period by the sharp rise in fossil fuel prices, which made older, less energy-efficient generating plants obsolete, and by the severe schedule and cost overruns that afflicted many nuclear power projects. The Clean Air Act and other environmental regulations enacted during the 1970s forced utilities to install expensive pollution-control equipment. In addition, rate-of-return regulation that put electricity pricing on to virtually a cost-plus basis weakened utilities' incentives to improve operating and capital efficiencies. Thus, conventionally measured multifactor productivity in the electricity sector declined at an annual average rate of -0.75 percent during the 1970s and fell further by -0.05 percent per year from 1979 through 1991.

Many of these tendencies have been reversed during the 1990s. Real energy prices have declined, and the industry's nuclear commitments have been sharply curtailed. Regulatory changes have promoted competition in electricity generation, spurring the growth of independent power producers operating high-efficiency gas and coal-fired turbine technologies.

ENVIRONMENTAL TRENDS

Although curtailed, environmental damage costs in the electricity sector still loom large. Data from the EPA Trends database on atmospheric emissions from the electric utility sector show that particulate emissions declined substantially after 1970 (USEPA, 1994). Power plant emissions of sulfur oxides, which almost doubled during the 1960s and by 1970 amounted to over half of the country's sulfur emissions, were stabilized and then moderately reduced in the next two decades. These modest declines in sulfur emissions represented well over half of the total sulfur abatement achieved throughout the economy over the period and lowered atmospheric concentrations of particularly damaging sulfate aerosols. By contrast, emissions of nitrogen oxides and volatile organic compounds increased, though less rapidly than the growth of electricity output. Despite this progress, the electric power sector remains a major source of air pollutants. In 1990, at the end of the period under review, the industry generated nearly two-thirds of all sulfur emissions and nearly one-third of total NOx emissions.

ENVIRONMENTAL DAMAGE COSTS

Many studies have estimated the damages that air emissions from the electricity generating industry cost the economy. The widely varying results, summarized in Table 2.1, reflect differences in geography, population density in the exposed areas, and pre-existing ambient air quality, as well as scientific uncertainties and methodological differences among the studies. Some studies considered a wider range of effects than others did—another reason why damage estimates differ.

In an earlier paper on productivity growth in the electric power sector, WRI used EPA mid-point estimates of $2,810/metric ton, $702/metric ton, and $253/metric ton in the year 1987 for particulate matter, sulfur oxides, and nitrous oxides, respectively (Repetto, 1990). EPA's Office of Planning and Policy Evaluation derived these estimates from several EPA-funded studies from the late 1980s (Energy & Resource Consultants, 1987; O'Connor, 1987). The types of damage considered for each emission varied: damages from particulates included mortality, acute and chronic morbidity, and soiling; damage from sulfur oxides included morbidity, materials damage, crop losses, and visibility losses, as well as morbidity from sulfate aerosol particulates; and from nitrogen oxides, visibility loss, eye and throat irritation, and materials damage.

In the late 1980s, the Bonneville Power Administration commissioned EcoNorthwest to study the pollution damages from a typical electric utility plant sited near cities of differing sizes east and west of the Cascade Mountains. These studies considered human mortality and morbidity, damage to materials, effects on visibility, and losses from damage to crops, livestock, timber, ecosystems, and endangered species. The BPA used the resulting values, shown in Table 2.1, in planning for system expansion (U.S. Congress, 1994).

Other important studies of the environmental damage costs from electric power plants include the joint U.S.-European Commission Fuel Cycle Study, the New York State Externalities Cost Study, and a study by Triangle Economics Research for Northern States Power (NSP) (Banzhaf, 1995; Rowe et al., 1995a, 1995b; Oak Ridge National Laboratory & RFF, 1994). All three studies examined the additional impact of a new or relicensed facility on air quality, given the existing level of emissions in the vicinity.

Table 2.1 **REVIEW OF MARGINAL DAMAGE ESTIMATES FROM AIR EMISSIONS ($/metric ton, 1987 prices)**

	Particulates	SO_2	NOx	VOC & CO
Repetto (1990)	2,810	702	253	
EPA NSPS (Elkins & Russell, 1985)	3,516	1,465		VOC: 1,460
BPA	West of Cascades: 1,502 East of Cascades: 163	West of Cascades: 3,513 East of Cascades: 395	West of Cascades: 862 East of Cascades: 67	
US-EC[1]	Knoxville: 3,210 Four Corners: 293	Knoxville: 54 Four Corners: 5		
New York State (Rowe, 1995)[2]	Rural 1: 2,915 Rural 2: 3,990 Suburban: 7,015 Urban: 39,902	Rural 1: 638 Rural 2: 665 Suburban: 729 Urban: 1,093	Rural 1: 820 Rural 2: 886 Suburban: 820 Urban: 1,002	
NSP (Banzhaf, 1995)	Urban: 4,561 Rural: 594 Met fringe: 2,042	Urban: 126 Rural: 15 Met fringe: 65	Urban: 287 Rural: 23 Met fringe: 76	CO: Urban: 1.53 Rural: 0.28 Met fringe: 0.97
EPRI (Koomey, 1990)[3]		Rural PA/WV: 948 sub. NY: 2,507	138	
NPC (Wang et. al., 1994)	in Las Vegas valley: 1,389 outside Las Vegas valley: 196		in Las Vegas valley: 215 outside Las Vegas valley: 176	

Notes:

1. Coal-fired plant
2. Central estimates for Natural Gas Combined Cycle facility
3. Best estimate

The U.S.-E.C. Fuel Cycle Study examined hypothetical power stations in the southeast United States (near Oak Ridge, Tennessee) and the Southwest (near Four Corners, Arizona). The study considered various impacts, but quantified only monetary damages from human mortality and morbidity and from damages to materials and crops. The New York State study considered sites throughout New York State and estimated damages to human mortality and morbidity, to crops and materials, to visibility, and to fishing in the Adirondack region. The NSP study in Minnesota accounted for impacts on human health, agricultural and materials damages, and loss of visibility. An important limitation of this third study is that it includes only the impacts

Table 2.2 | **MARGINAL DAMAGES FROM AIR EMISSIONS**

Pollutant	Marginal Damage Value ($/metric ton, 1987 prices)
Nitrogen Oxides (NOx)	841
Sulfur Oxides (SOx)	964
Particulates	3,192
Volatile Organic Compounds (VOCs)	1,460
Carbon Monoxide (CO)	1
Lead	1,384

Source: See text

within NSP's service area, though the damages extend well beyond those boundaries.

Other estimates were found in studies by the Nevada Power Company and the Electric Power Research Institute (reviewed by Wang et al., (1994) and Koomey, (1990) respectively), but few details were available on the methodologies used.

The New York State estimates were considered the most suitable for use in this research, partly because they take into account the damages from sulfate and nitrate particulates formed in the atmosphere from sulfur dioxide and nitrogen dioxide. (Particulate formation is ignored in both the US-EC and NSP studies, even though morbidity from sulfate particulates is 450 times higher than that from sulfur dioxide directly (O'Connor, 1987).) Moreover, because the New York State study considers damages over a broad geographical range, it captures the full impact of emissions. For example, in the New York State Rural-1 scenario, in which the plant is located centrally within the state, nearly half of the damages fell outside the state. In comparison, the US-EC study found that damages from sulfur dioxide and particulates were 4 to 5 times greater when the radius was extended from 50 miles to 1,000 miles around the site. (Among other things, particulates can reduce visibility over great distances.)

The importance of population density is evident from the large differences in damages from plants sited in urban, suburban, and rural locations. Though some older plants are sited in urban areas, this study conservatively emphasizes the values estimated for rural and suburban locations. Moreover, in view of regional variation, the values adopted for this study are an average of figures weighted to reflect the geographical distribution of electricity production within the United States.

For nitrogen oxides, sulfur oxides and particulates, the marginal damage values used in this analysis were derived from estimates from the New York State and BPA studies resulting in values of $841, $964 and $3,192/metric ton for nitrogen oxides, sulfur oxides and particulates respectively, in 1987 prices. For VOCs—a relatively minor power plant emission—the EPA New Source Performance Standards value from 1985 was used, updated to 1987. For carbon monoxide, a figure of $1/metric ton in 1993 was adopted as an approximate average of the figures quoted in the NSP study. The NSP study also provided the value used for lead damages. *(See Table 2.2.)*

These estimates refer only to a single year but actual damages probably varied from year to year,

influenced by two offsetting trends. On the one hand, in earlier years, emission rates were higher and air quality was poorer, suggesting that marginal damage costs per ton were probably higher. On the other hand, in earlier years, population and the size of the economy were lower, implying fewer victims of pollution and lower damage costs. To take these contradictory forces into account, these base estimates were extrapolated to other years using two alternative assumptions: one time series was generated by assuming that costs per ton were constant in real terms; another series was based on the assumption that costs per ton increased in proportion to the rise in real GDP. The former assumption implies significantly higher damages in earlier years thus resulting in higher rates of productivity growth once emissions trends are incorporated into the index.

ECONOMIC DATA

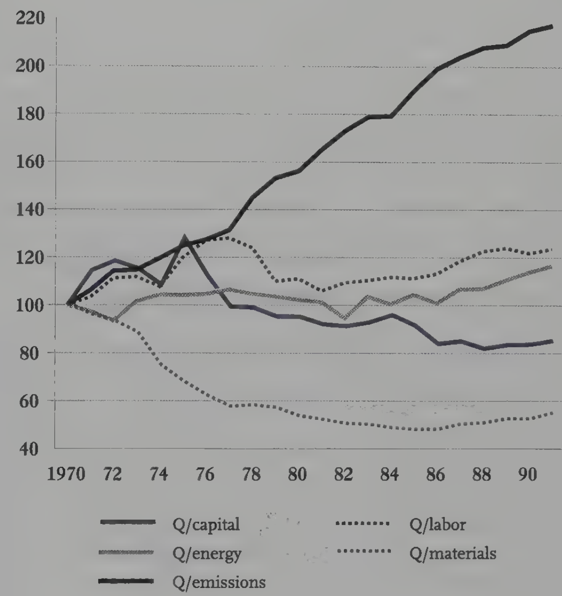
Jorgenson (1995) and the Bureau of Labor Statistics have both estimated economic outputs and inputs and conventional productivity measures at industry level. Their data differ slightly because they used different methods of treating quality changes and aggregation across subsectors. Although these variations result in some significant differences in single-factor productivities, the two data series yield similar estimates of multifactor productivity. Either data would provide an adequate benchmark from which to show the effects of revising the methodological approach. The Jorgenson data were adopted for this purpose, and the revised productivity growth rates were calculated from this baseline in the manner described in Chapter 1.

SINGLE-FACTOR PRODUCTIVITIES

The single-factor productivity estimates show how substantial the improvement in the industry's output mix has been, compared to its improvements in the use of inputs. Kilowatt hours produced per ton of atmospheric emissions has risen sharply, while labor productivity, capital productivity, and fuel efficiency have changed little over the past two decades. It seems that the conventional productivity indicator overlooks what has been the principal source of efficiency gains in the industry—the shift in its output mix toward higher valued products. *(See Figure 2.1.)*

Figure 2.1 SINGLE FACTOR PRODUCTIVITY IN THE ELECTRICITY SECTOR

1970 = 100



Source: Economic data from Jorgenson (1995)

Table 2.3

ELECTRICITY OUTPUT AND SHARE OF EMISSIONS DAMAGES WITHIN 'TOTAL OUTPUT'

		Constant Damage Values		Damage Values Proportional to GDP	
Year	Electricity Output \$1987m	Total \$1987m	Share in 'Total Output' (%)	Total \$1987m	Share in 'Total Output' (%)
1970	64,779	24,146	59.4	15,285	30.9
1971	68,505	23,437	52.0	15,260	28.7
1972	73,993	23,508	46.6	16,089	27.8
1973	77,417	25,033	47.8	18,023	30.3
1974	87,087	24,156	38.4	17,283	24.8
1975	95,638	23,832	33.2	16,912	21.5
1976	103,585	24,737	31.4	18,421	21.6
1977	113,377	25,348	28.8	19,728	21.1
1978	117,608	23,828	25.4	19,438	19.8
1979	122,314	23,417	23.7	19,584	19.1
1980	133,573	23,253	21.1	19,342	16.9
1981	139,900	21,860	18.5	18,505	15.2
1982	144,764	20,647	16.6	17,101	13.4
1983	150,034	20,598	15.9	17,725	13.4
1984	159,081	21,462	15.6	19,612	14.1
1985	159,676	20,382	14.6	19,215	13.7
1986	160,739	19,894	14.1	19,301	13.6
1987	161,237	20,053	14.2	20,053	14.2
1988	164,308	20,593	14.3	21,403	15.0
1989	162,753	20,851	14.7	22,220	15.8
1990	161,514	20,540	14.6	22,157	15.9
1991	154,896	20,303	15.1	21,740	16.3

To put it differently, the share of pollution damages in total output (including the value of "bads" as well as that of "goods"), which was very significant in the early 1970s, has fallen rapidly. Under the assumption of constant marginal damages over time, emissions accounted for approximately half of total output in the early 1970s and fell to about 15 percent in the late 1980s. *(See Table 2.3.)* Even then, the share of pollution damages within total output was still roughly equal to the individual shares of labor and energy within conventional output. Under the alternative assumption about the trend of per-ton damage costs over time, the decline in

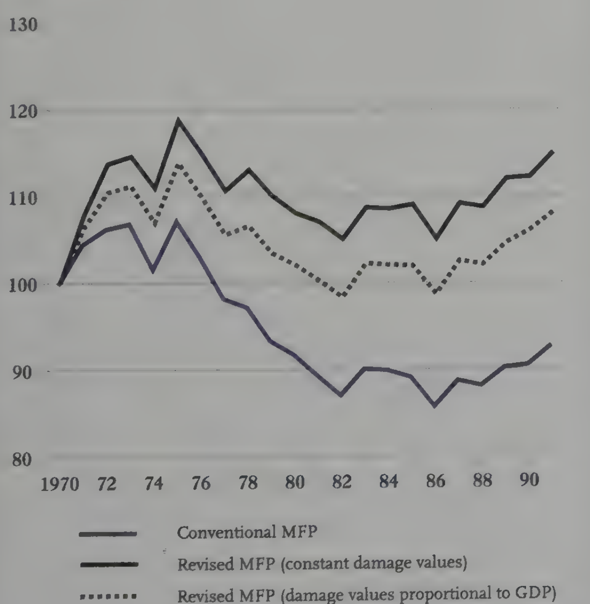
Table 2.4 **MULTIFACTOR PRODUCTIVITY IN THE ELECTRICITY SECTOR—CONVENTIONAL AND REVISED ESTIMATES**

Average annual percentage change

Period	Conventional MFP	Revised MFP (constant damage values)	Revised MFP (damage values proportional to GDP)
1970-79	-0.75%	1.02%	0.38%
1979-91	-0.05%	0.43%	0.37%
1970-91	-0.35%	0.68%	0.38%

Figure 2.2 **MULTIFACTOR PRODUCTIVITY IN THE ELECTRICITY SECTOR—CONVENTIONAL AND REVISED ESTIMATES**

1970 = 100



pollution's share in industry's outputs appears less dramatic, but still substantial. Revising the productivity index to take account of these large and declining shares would certainly alter the growth trend.

The share of environmental damages in total output would be even larger, of course, if CO_2 emissions and toxic air emissions were included. The electric power sector is a major source of both. Nearly a billion tons of carbon dioxide were emitted by the sector in 1970. Since then, carbon emissions have increased by 60 percent while electricity output has grown by 80 percent. The rising ratio of electricity output to carbon emissions, due to general efficiency improvements and a substitution away from coal, is a further source of productivity increase that the conventional productivity index doesn't capture.

MULTIFACTOR PRODUCTIVITY GROWTH

Incorporating this information on emissions trends, the standard productivity growth rate has been revised in accordance with equation (5) from the preceding chapter, under the two alternative assumptions about marginal demand costs. *(See Table 2.4 and Figure 2.2.)* The differences between the conventional and revised

estimates are striking. Although productivity as conventionally measured declined over the period, productivity actually increased substantially when the reduction in environmental damages is taken into account. Moreover, the largest difference between the conventional and the revised estimates arises in the 1970s, just when electric utilities were taking steps to reduce emissions in compliance with the Clean Air Act requirements.

3

ENVIRONMENT AND PRODUCTIVITY IN THE PULP AND PAPER INDUSTRY

The pulp and paper industry includes around 200 companies operating 569 separate facilities, but a dozen or so large companies account for most of its output (USEPA, 1995). It is the eighth largest U.S. manufacturing industry by value of sales. Over time, to achieve scale economies, plant sizes have been increased substantially. Consequently, heavy fixed capital costs make the industry quite sensitive to cyclical swings in demand. Energy and pollution control costs are also very significant cost elements. Not surprisingly, then, conventionally measured productivity trends have resembled those in the electricity sector. After average annual growth in multifactor productivity of 0.64 percent for the period 1947-73, productivity declined by -0.68 percent annually between 1973 and 1979, then leveled off over the 1980s (Jorgenson, 1995).

ENVIRONMENTAL DAMAGE

Papermaking involves mechanical and chemical processes that can generate significant air and water pollution. The main atmospheric emissions are sulfur compounds, particulates, and volatile organic compounds (VOCs) (USEPA, 1993b). Sulfur compounds are emitted during the pulping process, particulates emerge mainly from boilers and furnaces, and VOCs come from complex chemical process reactions, which also generate hazardous air pollutants that are increasingly subject to Clean Air Act regulation.

The pulp and paper industry is the largest industrial process water user in the United States and generates significant quantities of water effluents, especially suspended solids and biochemical oxygen demand (BOD) (USEPA, 1993a, 1993b). Total suspended solids (TSS) include dirt, grit, fiber, additives, and other solids released during production. These sediments

increase turbidity, interfere with aquatic plants and animals, and clog streambeds. The high organic content of materials in the waste stream raises the BOD of effluent water and stimulates algal growth or, at high levels, exhausts the dissolved oxygen. In addition, EPA's 1993 Toxic Release Inventory (TRI) showed total releases for the pulp and paper sector of 216 million pounds, an amount exceeded only by the Chemicals and Primary Metals sectors (USEPA, 1995). Many of these releases are chlorinated compounds discharged from bleaching processes.

The industry has incurred substantial environmental expenditures to comply with air, water, and toxic chemical regulations. Conventional water pollutants have been regulated by the Federal Water Pollution Control Act Amendments of 1972 and by the Clean Water Act of 1977, which restricted industrial effluents, including BOD and TSS, and forced pulp and paper plants to improve in-plant process controls and to install wastewater treatment plants (MEB, 1994). During the 1980s, a second wave of environmental regulation hit the pulp and paper industry when dioxins and other chlorinated organics were discovered in effluent streams. In the face of regulatory pressure and community fears about dioxins' health effects, manufacturers have changed production methods to reduce releases of these compounds (MEB, 1994) and to improve energy and water-use efficiency. Since 1988, total wastewater emissions have fallen by over half (USEPA, 1995). However, the industry is still the second biggest industrial discharger of TRI pollutants into surface waters.

EMISSIONS TRENDS

Over the 1970s and 1980s, atmospheric emissions fell despite the increase in paper output. Particulate emissions declined by 85 percent over the period. Sulfur, nitrogen, and volatile organic emissions fell more modestly, whilst carbon monoxide releases increased somewhat along with fuel combustion. These trends emerge from data collated by the EPA's Office of Planning and Program Evaluation (Pasurka, 1996). This source adds together figures on industrial process emissions in the sector and the pulp and paper industry's estimated share of industrial boiler fuel emissions, which are tracked for the entire industrial sector in the EPA Trends database.

Neither toxic air emissions nor carbon dioxide releases are evaluated in adjusting the multifactor productivity index, though both are significant. Energy-intensive operations generated about 185 million tons of carbon dioxide emissions in 1990, though the increasing use of biomass wastes for fuel implies that the industry, on balance, is a smaller source of atmospheric carbon than this figure suggests. Toxic releases to the atmosphere even in 1993 exceeded 190 million pounds of chemicals listed in the TRI, an amount second only to emissions from the Chemicals sector. Since carbon and toxic emissions also declined relative to paper output, they represent a further source of productivity gain. Yet, they were not included in the revised index because credible marginal damage estimates were not available. Also, since the TRI data were first collected only in the mid-1980s, earlier toxic emissions trends are unknown.

Waterborne effluents of suspended solids and BOD were reduced dramatically during the 1970s, by 60 and 83 percent respectively, because wastewater treatment, process controls, and materials recovery systems were improved. During the 1980s, however, these effluent flows

increased. The annual quantities of water effluents were estimated by multiplying NCASI survey data on average effluent loadings (in pounds per ton of production, by product class) by total production of paper, paperboard, and market pulp (American Forest & Paper Association, 1993; Miner & Unwin, 1993). These estimates were compared to EPA estimates from 1973, 1984, and 1989-90, and to recent data from the EPA's Permit Compliance System (PCS) and found to be generally consistent (Rubin, 1995; USEPA, 1993a). The NCASI series was available only up to 1988, so for the final two years, figures were derived from self-reported facility-by-facility data in EPA's Permit Compliance System.

MARGINAL DAMAGE ESTIMATES

Luken (1990) estimated the damage costs of additional BOD impairment while studying the benefits and costs of achieving the 1984 permit guidelines on BOD at 68 pulp and paper mills. For each mill location, his study first assessed BOD's impact on physical water quality in affected streams and lakes, then estimated the effect of water quality changes on water uses (drinking, swimming, fishing, boating, etc.) by using EPA water quality standards. Finally, Luken used results from earlier evaluations of the value of recreational water uses, combined with data on local population size, to calculate the monetary value of water quality improvements. Luken based his monetary estimates on three studies of recreation benefits of improved water quality on the Monongahela and Charles rivers (Smith & Desvouges, 1986; Smith et al. 1984; Gramlich, 1977). These were judged to be the most representative studies for sites close to pulp and paper mills.

Luken's results varied from mill to mill, reflecting differences in population, initial water quality, extent of improvement, and other factors. For this study, those estimates were aggregated into a national total by constructing a weighted average of the individual mill figures, with weights derived from the quantities of effluents released from each mill after it had met Clean Water Act requirements. Since the mills in Luken's sample were geographically representative of the industry as a whole, this procedure provides an estimate of the incremental damage cost per ton for the entire industry.

Estimated incremental damage costs range from a low estimate of $132/metric ton of BOD to a high value of $522/metric ton (1984 prices). The higher estimate includes "non-use values," the estimated amount people who don't actually use the particular water body for recreational purposes would be willing to pay to keep water quality from falling. Since these non-use values are not generally considered reliable, only the lower figure was used in the productivity calculations. This estimate includes only in-stream recreational damages from water-quality impairment from BOD and ignores other ecological and commercial impacts, so the estimated damage costs for BOD emissions are very conservative.

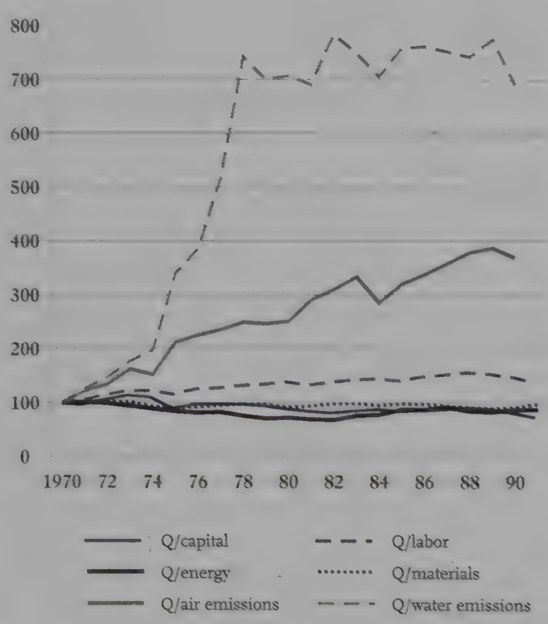
For total suspended solids, estimates of marginal damage were based upon the work of Ribaudo (1989a), who calculates damage costs per ton of soil erosion for ten agricultural regions of the United States. *(See Chapter 4, Table 4.3.)* These values had to be adjusted to reflect the fact that all pulp and paper effluent is discharged directly into surface waters, taking all sediment with it, but only some of the soil eroded from farm fields ends up in surface waters. The resulting values range from $1 to $30/metric ton, depending

Table 3.1 **MARGINAL DAMAGE VALUES FOR WATER POLLUTANTS**

Pollutant	Marginal Damage Value ($/metric ton, 1987 prices)
Total suspended solids (TSS)	7
Biochemical Oxygen Demand (BOD)	145
Source: See text	

Figure 3.1 **SINGLE FACTOR PRODUCTIVITY IN THE PULP AND PAPER SECTOR**

1970 = 100



Source: Economic data from Jorgenson (1995).

upon the region and whether one uses Ribaudo's low, 'best,' or high estimate. Using these results and regional production figures for the pulp and paper industry, the low, 'best,' and high estimates for marginal damage from TSS are $4.23, $7.20, and $13.80/metric ton ($1986). The best estimate converted to 1987 dollars used in this study is $7.43. *(See Table 3.1.)*

For atmospheric emissions, the marginal damage estimates developed for the electricity sector are also relevant to the pulp and paper industry given the broadly similar geographical distribution of electricity and pulp and paper plants.

ECONOMIC DATA

As in Chapter 2, the other economic data used in the multifactor productivity estimates are taken from an industry specific series provided by Jorgenson (1995). The conventional productivity growth rates were calculated from these data using equation (2) from Chapter 1.

SINGLE-FACTOR PRODUCTIVITIES

Figure 3.1 shows trends in single-factor productivities for the pulp and paper sector. Output per unit of emissions to air or water improved markedly, especially in the 1970s, far outpacing the other single factor productivities.

Table 3.2 PULP AND PAPER OUTPUT AND SHARE OF POLLUTION DAMAGES WITHIN 'TOTAL OUTPUT'

		Constant Damage Values		Damage Values Proportional to GDP	
Year	Pulp & Paper Output $1987m	Total $1987m	Share in 'Total Output' (%)	Total $1987m	Share in 'Total Output' (%)
1970	68,927	4,942	7.7	3,128	4.8
1971	66,920	4,420	7.1	2,878	4.5
1972	71,226	4,304	6.4	2,946	4.3
1973	77,739	3,695	5.0	2,660	3.5
1974	91,295	3,427	3.9	2,452	2.8
1975	83,222	2,699	3.4	1,915	2.4
1976	90,617	2,641	3.0	1,967	2.2
1977	91,704	2,633	3.0	2,049	2.3
1978	92,938	2,502	2.8	2,041	2.2
1979	97,680	2,484	2.6	2,078	2.2
1980	99,600	2,458	2.5	2,045	2.1
1981	99,711	2,100	2.2	1,778	1.8
1982	93,437	2,105	2.3	1,743	1.9
1983	95,521	2,058	2.2	1,771	1.9
1984	103,032	2,378	2.4	2,173	2.2
1985	98,405	2,228	2.3	2,100	2.2
1986	101,002	2,222	2.2	2,156	2.2
1987	109,739	2,159	2.0	2,159	2.0
1988	118,820	2,054	1.8	2,134	1.8
1989	121,867	2,008	1.7	2,140	1.8
1990	116,856	2,108	1.8	2,274	2.0

Particularly dramatic is the increase in paper output per unit of water effluents. Clearly, the main source of productivity growth was the improvement in the industry's product mix: for every ton of paper, it produced less and less pollution, an important—but overlooked—source of efficiency gain.

MULTIFACTOR PRODUCTIVITY GROWTH

The standard productivity growth rate was adjusted using equation (5) from Chapter 1 for both series of marginal damage values. The assumption that damages increase in proportion to GDP has the effect of reducing the damages in earlier years, when population and recreational water demand were smaller. The assumption that damages are constant in real terms gives more weight to the fact that in earlier years water quality degradation was more severe, so that marginal effluent damages might have been higher.

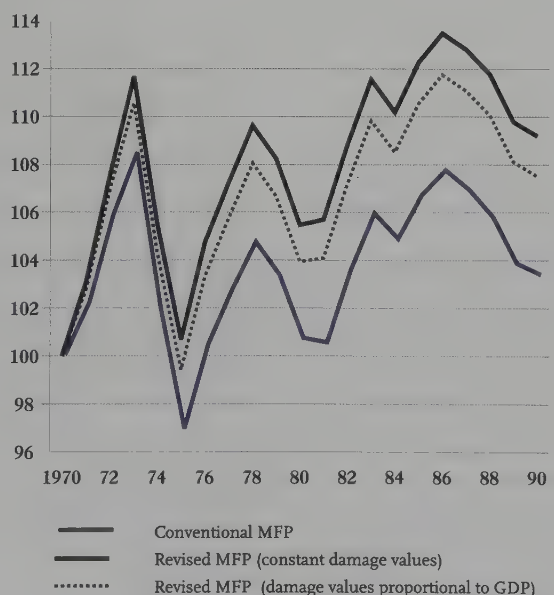
Table 3.3 **MULTIFACTOR PRODUCTIVITY IN THE PULP & PAPER SECTOR—CONVENTIONAL AND REVISED ESTIMATES**

Average annual percentage change

Period	Conventional MFP	Revised MFP (constant damage values)	Revised MFP (damage values proportional to GDP)
1970-79	0.36%	0.88%	0.72%
1979-90	0.00%	0.08%	0.07%
1970-90	0.16%	0.44%	0.36%

Figure 3.2 **MULTIFACTOR PRODUCTIVITY IN THE PULP AND PAPER SECTOR—CONVENTIONAL AND REVISED ESTIMATES**

1970 = 100



Overall, pollution damages range from 2 to 8 percent of the value of total output, considerably smaller than in the electricity sector. *(See Table 3.2.)* As a result, omitting pollution damages from the productivity index should lead to a smaller distortion. Nonetheless, the revised index shows considerable differences from the conventional estimates, especially during the 1970s, when most of the environmental improvement took place. *(See Table 3.3.)*

Over the entire period 1970 to 1990, the revised series implies that productivity in the pulp and paper industry grew by twice as much as the conventional estimates imply. *(See Figure 3.2.)* For the whole period, the productivity growth attributable to environmental improvement was larger than that attributable to all the conventional factors combined. The most dramatic difference is found in the earlier years of the period, when the industry was rapidly changing its output mix to reduce the "bads" it generated relative to the "goods" it produced. These results again demonstrate how misleading the current methodology can be when applied to pollution-intensive industries.

4

ENVIRONMENT AND PRODUCTIVITY IN AGRICULTURE

Although agriculture's share in GDP has shrunk continuously for decades, the sector still employs 3.5 million people directly and millions more work in related industries. U.S. agriculture is also important internationally. Total farm exports of $54 billion, though only about 10 percent of total U.S. merchandise exports, constituted 23 percent of world agricultural exports in 1995, making the United States the single largest agricultural exporter (USDA, 1996a).

Agriculture in the United States has demonstrated the capacity for sustained growth in output and productivity. From 1948 to 1993, total output more than doubled while agricultural acreage shrank and overall input use declined by about 3 percent. Multifactor productivity growth in agriculture has averaged 1.8 percent per year over the period, an enviable record. *(See Table 4.1.)* This achievement stems from technological change in the mix and the quality of inputs.

Between 1948 and 1993, the use of intermediate inputs (energy, chemicals, feed, seed, and purchased livestock) rose at an annual average rate of 1.3 percent and the use of capital increased by 0.7 percent per year, but labor input declined at the rapid rate of 2.7 percent per year over the period (USDA, 1996b). Improved seeds, mechanization, and especially the increased use of fertilizers, herbicides, and other chemical pesticides have transformed American agriculture (USDA, 1994b).

ENVIRONMENTAL IMPACTS

This record of growth and transformation has had important environmental impacts. Agriculture inevitably has significant ecological repercussions because cropland, rangeland, and pasture together occupy half the total land area of the contiguous 48 states. Moreover, throughout the postwar period, agricultural support programs encouraged farmers to cultivate more

Table 4.1 **MULTIFACTOR PRODUCTIVITY GROWTH IN THE AGRICULTURAL SECTOR (1948–93)**

Year	Average Annual Percentage Change
1948-53	1.1
1953-57	0.8
1957-60	2.5
1960-66	1.8
1966-69	2.8
1969-73	2.1
1973-79	1.4
1979-89	2.7
1989-93[1]	-0.1[2]
1948-93	1.8

1. All periods except 1989–93 represent complete business cycles
2. Productivity decline is largely due to the exceptional flooding of the Mississippi and Missouri river basins in 1993 which produced the smallest feed grain and oilseed harvests in five years (USDA, 1996).

intensively by ensuring high farm output prices; by subsidizing agricultural research, irrigation, and other inputs; and by restricting the acreage that could be planted (Faeth, 1995). Partly as a consequence of these support programs, agriculture is now dominated by large specialized farms that plant the same few crops year after year and rely on chemicals to maintain soil fertility and keep pests at bay. Such operations are vulnerable to wind and water erosion that carries off nutrients and chemicals along with exposed topsoil. In 1992, more than 2 billion tons of topsoil eroded from America's farmlands, and much of it ended up as sediment in the nation's waterways. Heavily applied farm chemicals drain into surface waters and leach into subsoil aquifers. Nitrates and pesticide residues are found in wells that supply drinking water throughout the farmbelt, and farm run-off is a major contributor to eutrophication and algal growth in surface waters. Agriculture has become the country's largest non-point pollution source and the primary pollution source of most rivers and lakes affected by non-point pollution (National Research Council, 1989; Smith et al., 1987).

These environmental problems create economic costs. In the case of wind erosion, costs take the form of increased cleaning, maintenance, and replacement expenditures. Runoff, erosion, and deposition into water bodies increases water treatment and watercourse maintenance costs and reduces recreational value. Eutrophication changes the marine ecology, sometimes impairing fisheries and recreational uses. Chemical contamination of ground and surface waters can poison wildlife and ecosystems. At sufficiently high levels, it can also threaten human health.

Although environmental damage from agriculture takes many forms, the only effects for which economic costs have been estimated satisfactorily are those from sheet and rill soil erosion.[1] Sediment and silt builds up to fill reservoirs, block navigation channels, and interfere with water conveyance systems (Ribaudo, 1989a). Increased flooding may result. Eroded material also harms aquatic ecosystems and may limit fishing and boating. One study estimated the total off-site costs of

eroding cropland at nearly $3.5 billion per year (Clark et al., 1985).

TRENDS IN EROSION

In recent years, soil erosion has been reduced—especially from cropland, from which total erosion fell by 30 percent from 1982 to 1992. Although a variety of federal programs encourage soil conservation, including cross-compliance programs that penalize farmers who plough up highly erodible soils, the main reason for this decline has been the temporary retirement of cropland enrolled in the Conservation Reserve Program (CRP). Under this initiative, land is removed from cultivation and put under a protective cover of grass or trees. Farmers are paid half the cost of developing the cover and receive yearly payments to compensate for lost income (Ribaudo, 1989b). Introduced in 1986, the program succeeded in taking 36 million cropland acres out of production by 1993, reducing annual soil erosion by an estimated 690 million tons (USDA, 1994b). By USDA estimates, all federal programs together have reduced agricultural erosion by more than a billion tons. (Faeth, 1995, p. 30; USDA 1993).

Market forces have also helped reduce erosion. The rise in energy prices in the late 1970s prompted many farmers to adopt no-till or reduced-till farming systems, reducing their mechanical working of the soil before planting, and relying on chemical herbicides rather than mechanical tillage for early weed control. The U.S. Department of Agriculture's Natural Resources Inventory (USDA, 1994a, 1979) estimates erosion rates from cropland, pasture, and rangeland in each state, along with the area devoted to various land uses within each state. Four National Resources Inventories have been completed, one every five years since 1977. The NRI data were used to calculate the total quantity of soil erosion in each of the contiguous 48 states, and these figures were aggregated into the total tonnage of erosion within each agricultural production region,[2] the geographic level at which erosion damage costs have been estimated.

Erosion rates were calculated using the Universal Soil Loss Equation, with parameter values adjusted for each land use in each state. As part of the 1992 NRI, the USDA adopted new parameter values capturing the effect of soil cover on erosion rates, estimated for each crop. To make its 1982 and 1987 soil erosion estimates consistent with the 1992 inventory, it revised them using the new parameter values. The results show that total sheet and rill erosion in the United States fell significantly between 1982 and 1992. The most dramatic decline occurred on cropland, where total erosion fell 30 percent from 1.7 billion tons per year to 1.19 billion tons

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1 Sheet erosion is "the removal of a fairly uniform layer of soil from the land surface by runoff water". Rill erosion is "an erosion process in which numerous small channels of only several centimeters in depth are formed; mainly on recently cultivated soils" (Brady & Weil, 1996).

2 For analytical purposes, the lower 48 states are divided into ten standard regions (Appalachia, Corn Belt, Delta States, Lake States, Mountain, Northeast, Northern Plains, Pacific, Southeast, Southern Plains), each comprising two or more states.

Table 4.2 **TOTAL SHEET AND RILL SOIL EROSION BY PRODUCTION REGION (1977-92)**

(thousands of tons)

	1977	1982	1987	1992
Appalachia	261,585	208,276	195,851	154,970
Corn Belt	760,894	654,319	536,189	427,309
Delta	173,474	128,848	110,685	91,200
Lake States	122,809	128,197	123,129	101,884
Mountain	521,188	300,411	283,902	276,020
Northeast	86,812	68,426	66,679	56,322
Northern Plains	422,963	334,545	317,882	267,893
Pacific	194,600	167,060	151,965	130,951
Southeast	117,132	97,301	79,391	63,573
Southern Plains	546,405	262,166	252,287	227,885
US TOTAL	**3,207,862**	**2,349,548**	**2,117,961**	**1,798,007**

Source: USDA (1994a, 1990, 1979). See text for derivation of 1977 figures.

per year. Erosion from land in pasture declined by about 15 percent, from 139 million to 125 million tons per year. Rangeland erosion in 1992 declined by 6 percent from its 1982 level of 509 million tons per year.

However, since the USDA did not go back and adjust the parameter values for the 1977 NRI, figures for that year are inconsistent with the other estimates. Erosion rates quoted in the 1977 NRI for pasture and rangeland are up to two or three times higher than those estimated for 1982, a change that cannot be explained by technological or policy changes. Therefore, the 1977 figures were adjusted in light of the revisions made to 1982 and 1987 figures. The 1977 figures were revised in the same proportions as their 1982 and 1987 counterparts, state by state and land use by land use. That is, each 1977 erosion estimate in the original NRI was adjusted to 1977_A where:

$$1977_A/1977_U = (1982_A/1982_U + 1987_A/1987_U)/2$$

and where the subscripts indicate adjusted and unadjusted figures. These adjusted figures were then re-aggregated to the level of the production regions.

However, the adjustments make only a small impact on the final figures, merely reducing the estimate of total erosion in the United States from 3.3 billion to 3.2 billion tons. The estimated erosion rates for 1977 remain markedly higher than those for subsequent years. *(See Table 4.2.)*

Table 4.3 **ESTIMATES OF THE OFF-FARM COSTS OF SOIL EROSION ($/metric ton, 1986 prices)**

Production Region	Low	Best	High
Appalachia	0.78	1.42	2.26
Corn Belt	0.56	1.15	2.03
Delta	1.50	2.45	8.19
Lake States	2.00	3.74	6.01
Mountain	0.63	1.12	1.72
Northeast	4.21	7.06	14.11
Northern Plains	0.32	0.57	2.53
Pacific	1.53	2.48	4.76
Southeast	1.17	1.92	2.71
Southern Plains	1.15	2.02	3.89

Source: Ribaudo (1989a)

THE COSTS OF EROSION

The off-farm costs from sheet and rill soil erosion have been estimated by adding up figures for twelve kinds of damage, including impeded water flow in roadside ditches and irrigation canals, extra treatment costs incurred by water users, and loss of fishing opportunities (Ribaudo, 1989a). Although these estimates are the most comprehensive ones available, they are still incomplete and probably underestimate the true damage costs. Adverse effects on recreational activities other than fishing are ignored, for example.

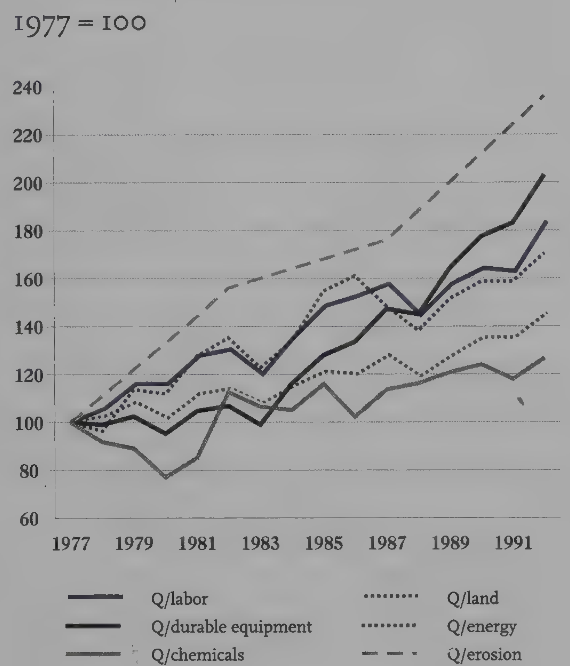
High, low, and "best" estimates of damage costs per ton of soil eroded were made for each production region in the country. *(See Table 4.3.)* Damages vary substantially among regions. They are highest in the Northeast, where rivers drain into the densely populated eastern seaboard and where the demand for water and water-related recreation is extensive. Costs are lowest in the dry and sparsely populated Northern Plains.

Table 4.4 **AGRICULTURAL OUTPUT AND SHARE OF EROSION DAMAGES WITHIN 'TOTAL OUTPUT'**

		Constant Damage Values		Damage Values Proportional to GDP	
Year	Agricultural Output $1987m	Total $1987m	Share in 'Total Output' (%)	Total $1987m	Share in 'Total Output' (%)
1977	109,827	5,543	5.3	4,315	4.1
1982	159,730	4,105	2.6	3,401	2.2
1987	159,607	3,746	2.4	3,746	2.4
1992	194,100	3,177	1.7	3,489	1.8

Figure 4.1

SINGLE FACTOR PRODUCTIVITY IN THE AGRICULTURE SECTOR



Source: Economic data from "Economic Report of the President," 1996, Tables B-95 and B-96

Regional erosion quantities were multiplied by the regional costs per ton to determine overall regional damage values, and these were added up to arrive at an estimate of total national damages, as required for the multifactor productivity analysis. *(See Table 4.4.)* If damage costs per ton are assumed to have remained constant, the real value of erosion damages has fallen steadily over the period, but under the assumption that damage costs per ton grew in proportion to GDP, total damages rise and then decline.

SINGLE-FACTOR PRODUCTIVITY

The agriculture sector achieved rising output per unit of labor, capital, and materials between 1977 and 1992, in keeping with its favorable record of multifactor productivity growth. *(See Figure 4.1.)* Again, though, the increase in output per unit of soil erosion outpaced all other sources of productivity gain, and this source of improvement is left out of the conventional indicator.

MULTIFACTOR PRODUCTIVITY

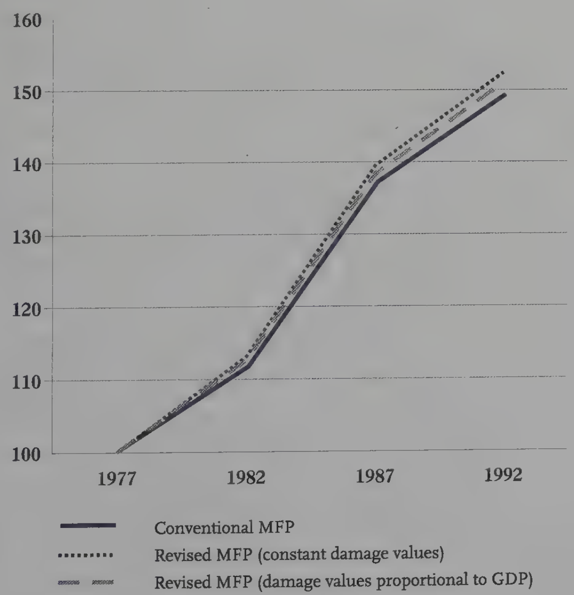
Adjusting the conventional multifactor productivity estimates required expressing erosion damages as a share in "total" agricultural output (marketed output and environmental damage together). Under one assumption, these costs fell from more than 5 percent to less than 2 percent of the value of total output from the sector. However, the value of farm commodity outputs is inflated by a variety of price support programs, so the true importance of environmental damages is somewhat understated by these figures.

The USDA calculates multifactor productivity growth rates for U.S. agriculture using the conventional methodology outlined in Chapter 1 (USDA, May 1996; Ball et al., 1995). These estimates were adjusted for off-site erosion using the same methodology applied in preceding chapters. Sediment run-off is considered an unwanted farm output. However, because erosion estimates are made only at five-year intervals, productivity growth rates have been expressed as five-year average annual growth rates. Average rates of change for erosion damages were derived by assuming constant rates of change over the five year periods between NRIs. *(See Table 4.5 and Figure 4.2.)*

Table 4.5 **MULTIFACTOR PRODUCTIVITY IN THE AGRICULTURE SECTOR—CONVENTIONAL AND REVISED ESTIMATES (Average annual percentage change)**

Period	Conventional MFP	Revised MFP (constant damage values)	Revised MFP (damage values proportional to GDP)
1977-82	2.19%	2.50%	2.41%
1982-87	4.20%	4.28%	4.20%
1987-92	1.71%	1.78%	1.76%
1977-92	2.30%	2.41%	2.38%

Figure 4.2 **MULTIFACTOR PRODUCTIVITY IN THE AGRICULTURE SECTOR—CONVENTIONAL AND REVISED ESTIMATES**



CONCLUSIONS

The revised estimates of productivity growth are higher than the conventional ones. However, compared to the results for the electricity sector and the pulp and paper sector, the adjustments are relatively small. At most, the adjusted productivity growth rates are approximately 14 percent higher (equivalent to 0.31 percentage points). The differences are comparatively small because erosion damages are estimated to average less than $2 per ton in 1986,[3] so environmental costs are but a small fraction of total output.

Nonetheless, these damage costs only partially capture agriculture's environmental impacts. Extending the scope of the study to include damages from chemical and nutrient run-off and wind erosion would probably reveal a greater differential between conventional and adjusted measures. For example, one study found that

3. The analysis was also conducted using Ribaudo's high estimates, which led to erosion shares of 4 to 6 percent for the years 1982-92, a slight increase still relatively insignificant compared to the contribution of damages to 'total' output in the electricity sector.

off-farm wind erosion costs may be of similar magnitude to off-farm water erosion costs (Huszar, 1989) and wind erosion probably also declined as soil cover improved.

Moreover, reductions in soil erosion also contributed to conventionally measured productivity gains by stemming the loss of on-farm soil fertility. Topsoil losses deprive the land of important nutrients and microorganisms, and diminish moisture retention capacity. Reducing erosion rates over these years helped boost per acre production, an effect reflected in the conventional productivity measure. In short, reducing on-farm and off-farm erosion damages through conservation programs raised productivity in U.S. agriculture.

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